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Policy Study on Adjustments to Electric Power Prices for China's Air Pollution Abatement

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ABSTRACT

In the past decade, the deterioration in atmospheric quality caused by emissions of ambient particulate matter with an aerodynamic diameter of less than 2.5 μm (PM2.5) has become an urgent problem in China. As this problem can be mainly attributed to the large amount of coal consumption, a strategy to promote electric power substitution was initiated, and in this case, cutting the price of electricity is considered useful. However, since it was announced that the price of electric power used in the service industry will be reduced by 10%, the proper target to cut the price of electric power used in the secondary industry was under debate. By using the computable general equilibrium (CGE) model, the policy to cut the price of electric power used in the secondary industry was simulated and the effects of the policy on the economy and the environment were explored. The results show that the policy to cut electric power prices will contribute to promoting the strategy of electricity substitution, and further contribute to environmental improvement. This policy can result in positive effects on the systems of the economy and the environment at the same time, and when the target to cut the price of electric power used in the secondary industry is –3%, the maximum positive effects will be obtained: gross domestic product (GDP) growth will be accelerated by 0.015‰, while $PM_{2.5}$ emissions will be abated by 394.2 tons. Moreover, based on the unique cross-subsidy mechanism in China's electric power industry, although residents' consumption welfare can be fully compensated, less cross-subsidy will have a negative effect on the agriculture industry.

INTRODUCTION

In the past decade, China was suffering from the serious problem of air pollution. Especially, the ambient particulate matter with an aerodynamic diameter of less than 2.5 μm ($PM_{2.5}$) has led to frequent hazy weather. According to the Annual Report of Environmental Statistics in China, 2014, the amount of dust particles (including $PM_{2.5}$) emitted into the atmosphere was 17.408 million tons. According to China's Air Quality Report, in March 2018, the average $PM_{2.5}$ concentration in China's 10 main cities was approximately 5.5-7.3 times higher than the World Health Organization (WHO) safety standards (15 μg/m^3). Therefore, improving the air quality in China is an urgent issue.

It is already acknowledged that, the cause of $PM_{2.5}$ emissions in China can be mostly attributed to the high percentage taken by coal at the final consumption of energy (Zhu 2016). In this case, the Chinese government promoted a strategy of electricity substitution at the final consumption of energy. This strategy is expected to reduce $PM_{2.5}$ emission.

In order to encourage electric power consumption, the Chinese government further started to intervene and adjust the consumption prices of electricity. Experiments to cut the electricity prices for the uses in secondary industries has been attempted in a number of provinces, and in 2018, the Chinese prime minister Keqiang Li put forward a policy to cut the electricity price in the service industry by 10%.

However, the existing cross-subsidization mechanism in the electricity consumption price complicates the situation. As the secondary and service industries provide electricity consumption subsidies to residents and the agriculture, the policies to cut electricity prices may finally harm residents' consumption welfare. In addition, it is also worth discussing whether electricity substitution will lead to a positive environmental effect. In China, as more than 60% of electricity is generated by coal-fired power, and electricity substitution will increase the electricity demand, it may also result in increased coal consumption, because more coal would be needed for electricity generation.

Therefore, a comprehensive judgment is needed in making a proper policy for air pollution abatement. This study focuses on the two issues of whether the strategy of electricity substitution will promote environmental quality, and what is the proper policy for the strategy of electricity substitution.

STATE OF ART

Energy is the driving force of human civilization (Zhang

2013). The relationship between energy and economy was not confirmed until the empirical study made by Kraft et al. (1978). In later decades, this relationship was discussed in a number of other countries. Some scholars consider it bidirectional (Akkemik et al. 2012, Liddle et al. 2015), while others consider not (Dergiades et al. 2013, Hamit 2012), but the bidirectional relationship exists in China (Lu 2017).

The dualistic relationship was developed in the 1990s, when the environmental issue was taken into consideration. Nordhaus et al. (1996) were the pioneers, and the famous inverted U-shaped environmental Kuznets curve became the theoretical foundation for further studies (Wang et al. 2015). Based on these studies, the energy–economy–environment integrated (3E-integrated) system was constructed. This is an interrelated system in which energy policy will affect the three systems directly (Vera et al. 2007, Lu et al. 2017).

As the current serious problem of haze pollution in China is caused by energy consumption, some scholars have begun to analyse it and call for the strategy of electricity power substitution (Xu et al. 2017). Undoubtedly, if the policy is implemented, it will have an impact on the economy and lead to environmental effects. Meanwhile, it was found that a unique industrial mechanism, the cross-subsidy mechanism in electricity prices, may be used as an effective tool in electricity policy-making for positive economic and environmental effects (Qiao et al. 2018).

The computable general equilibrium (CGE) model is a useful tool to analyse policy shocks to the 3E-integrated system (Céline et al. 2009), and scholars have analysed how different energy policies would shock the 3E-integrated system by using the CGE model (Hélène et al. 2012, Christopher et al. 2017). But there are few studies on the following three issues: whether the current policy of cutting electricity will contribute to the strategy of electricity substitution, how the policy of electricity substitution will shock the 3E-integrated system in China, and what the proper policy details should

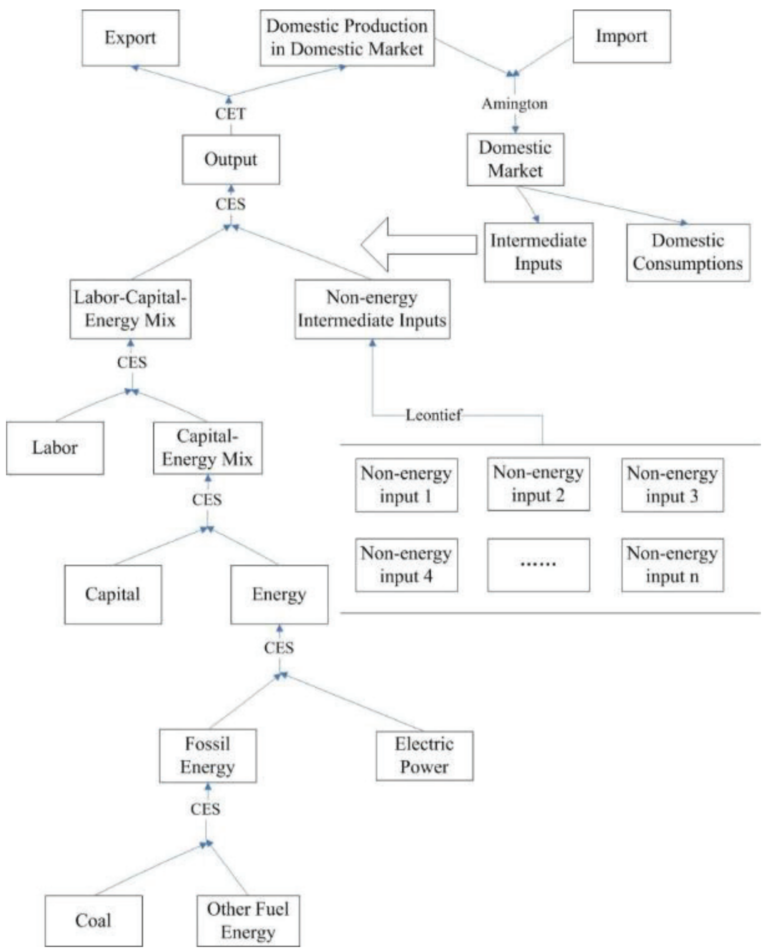

Fig. 1: Structure of computable general equilibrium (CGE) model.

be. We can use the CGE model to simulate the policy of electricity substitution, and analyse the issues above by evaluating the policy shocks.

MATERIALS AND METHODS

Cross-subsidies in electricity consumption are reflected by the distortion coefficients in electricity prices in different industries. As the electricity prices of intermediate inputs in some sectors are adjusted exogenously, while those of agriculture and residents are set as unchanged, the distortion coefficients can be the policy tools. In order to simulate the effects of this policy, we construct a corresponding static CGE model. By integrating and subdividing the relevant industrial sectors in the statistics, the model is composed of four energy sectors and seven non-energy sectors. Capital and labour are the essential production factor inputs, and the distortion coefficients of factor inputs are also introduced. Residents, enterprises, and the government are included in the domestic economic entities. The sectors are divided into non-energy and energy sectors. The non-energy sector industries are as follows: agriculture (number 1), heavy mining and processing (2), light industry (3), chemicals (4), manufacturing (5), other secondary industries (6), and service (7). The energy sector contains the following: fossil energy, including coal mining and processing (8), other fuel energy mining and processing (9), and electric power generation and supply (10).

Construction of CGE Model

The model used in this study is shown in Fig. 1, the mathematical links between different intermediate commodity and factor inputs are depicted by groups of production functions. The model is made up of two bundles: The bundle of non-energy intermediate inputs is a Leontief structure, to reflect the assumption of weak substitution between different non-energy intermediate commodities; the other bundle comprises production factors and energy intermediate inputs. Besides the Leontief production functions, the other production function in this block is the constant elasticity of substitution (CES).

The CES production function is written as:

$$QA_i = \alpha_i \cdot \left[\delta_i \cdot x_{1i}^{\frac{\varepsilon_i - 1}{\varepsilon_i}} + \left(1 - \delta_i\right) \cdot x_{2i}^{\frac{\varepsilon_i - 1}{\varepsilon_i}} \right]^{\frac{\varepsilon_i}{\varepsilon_i - 1}} \quad \ldots(1)$$

Where, i indicates the serial number of the sector, QA_i indicates the output quantity of the sector's production, α_i indicates the scale factor in the production of sector I, x_{1i} and x_{2i} indicate the quantities of intermediate inputs in the production of sector I, δi indicates the share parameter between x_{1i} and x_{2i}, and εi indicates the elasticity of substitution between x_{1i} and x_{2i}.

For maximum profit and minimum cost, the optimization solution for Formula (1) will be obtained when the following condition is achieved:

$$\frac{p_{1i}}{p_{2i}} = \frac{\delta_i}{(1-\delta_i)} \cdot \left(\frac{x_{2i}}{x_{1i}}\right)^{\frac{1}{\varepsilon_i}} \quad \ldots(2)$$

Where, p_{1i} and p_{2i} indicate the prices of the two intermediate inputs. The Leontief production function can be treated as a special CES production function (when the elasticity of substitution is infinitesimal) and can be written as:

$$QINTA_{ij} = ia_{ij} \cdot QINTA_j \quad \ldots(3)$$

Where, i and j indicate the serial numbers of sector production, $QINTA_{ij}$ indicates the quantity of intermediate inputs i used in the production of sector j, $QINTA_j$ indicates the total of all intermediate inputs used in the production of sector j, and ia_{ij} indicates the input–output coefficient. For profit maximization, the solution for Formula (3) will be obtained when the following condition is achieved:

$$PINTA_j = \sum_{i=1}^{n} ia_{ij} \cdot PA_i \quad \ldots(4)$$

where $PINTA_j$ indicates the average cost of production of sector j, and PA_i indicates the cost of intermediate inputs i.

Modelling for Subsidy Mechanism in Electricity Consumption Price

The unique cross-subsidy mechanism in electricity consumption pricing has led to price distortion among industries. Although it is still unknown how the subsidy mechanism should be improved, the price distortion coefficients can be the tools to adjust the energy consumption structure.

$$PE_{\text{ave}} = \frac{\sum_{i=1}^{n} PE_i \cdot QE_i}{\sum_{i=1}^{n} QE_i} \quad \ldots(5)$$

Where, PE_{ave} indicates the average price of electricity consumption; n indicate the number of electricity consumption prices kinds; QE_i and PE_i indicate the electricity consumption quantity and price for the specific kind i. Based on Formula (5), the price distortion coefficients of electricity consumption, and the cross-subsidies can be calculated by

$$\begin{cases} e_i = \dfrac{PE_i}{PE_{ave}} \\ S_i = (1-e_i) \cdot PE_{ave} \cdot QE_i \end{cases} \quad \ldots(6)$$

Therefore, the policy of cutting the price of intermediate electricity input in the secondary and service industries is transferred to adjust the distortion coefficients of *ei*.

Calculation Method of Residents' Consumption Welfare

The policy shock on the 3E-integrated system is judged by changes in economic and environmental indicators.

Among the economic indicators, the macroeconomic indicators of GDP and CPI are chosen, and the changes of sector outputs can be used to evaluate the policy effects. Moreover, it is important to observe the changes in residents' consumption welfare: residents' expenditure function used in this model is the LES function, which is developed from the Stone–Geary utility function:

$$\begin{cases} u(Q) = \prod_{i=1}^{n} (q_i - \gamma_i)^{\beta_i} \\ \sum_{i=1}^{n} \beta_i = 1 \end{cases} \quad \ldots(7)$$

Where, $u(Q)$ is the residents' utility function, Q indicates the column vectors of commodity demands, n indicates the number of sectors, i indicates the sector's serial number, q_i indicates the commodity demand of sector i, γ_i indicates the necessity demand of sector i, and β_i indicates the marginal share of consumption. The indicators of equivalent variation (EV) and compensate variation (CV) are known as:

$$\begin{cases} EV = e(P0, u(QH1)) - E(P0, u(QH0)) \\ CV = e(P1, u(QH1)) - E(P1, u(QH0)) \end{cases} \quad \ldots(8)$$

Where, $e(P0, u(QH1))$ and $e(P0, u(QH0))$ are the expenditure functions; $P0$ and $QH0$ are the column vectors of commodity sales prices and demands, respectively, before the policy implementation; $P1$ and $QH1$ are the column vectors of commodity sales prices and demands respectively, after the policy implementation. Bringing Formula (7) into Formula (8), EV and CV can be calculated.

Calculation Method of Environmental Effects Evaluation

The policy shock will show its effects on the economy and the environment at the same time, but it is difficult to evaluate the environmental effects, because it is difficult to obtain the emission coefficients. Considering that emission coefficients are different among industries and among the types of energy, we try to evaluate the environmental effects though the economic effects.

As the two systems of environment and economy are integrated and energy consumption is positively correlated with pollution emissions, the emission coefficient can be described as

$$E_{j,k} = \sum_{i=1}^{n} (\lambda_{i,j,k} \cdot C_i) \quad \ldots(9)$$

Where, j indicates the type of energy, k indicates the type of pollution, $E_{j,k}$ indicates the pollution emissions caused by the consumption of energy j, i indicates the industry consuming energy j, C_i indicates the quantity of consumption of energy j in industry i, and $\lambda_{i,j,k}$ indicates the emission coefficient of industry i. The linear relationship between pollution emissions and energy consumption in Formula (9) can be considered valid when the change rate of C_i is slight under the policy shock.

$E_{j,k}$ can be directly obtained from the statistics and C_i can be known from the social accounting matrix (SAM), then $\lambda_{i,j,k}$ can be calculated and treated as a constant parameter. Under the policy shock, the economic system will slightly change the structure of energy demand, then the environmental effects can be evaluated.

Data and Parameters

The social accounting matrix (SAM) is the most important base data for the CGE model, because it fully describes the economic system and the equilibrium relationships. The data in the SAM are from the input–output table of 2015, the *2017 China Financial Year Book*, and the *2017 China Statistical Year Book*. We use the maximum entropy method to adjust the SAM into balance.

The substitution elasticities are collected from study by He et al. (2017), and the environmental emission coefficients (that cannot be found in the statistics) are from a study by Huo et al. (2014).

SIMULATION RESULTS

As the Chinese government has clearly announced a cut in the price of electric power used in the service industry by 10%, and debates are focused on the proper target to cut the price of electric power used in the secondary industry. In this study, the baseline scenario is that the price of electric power used in the secondary industry is not changed; we set 10 scenarios, with the target of cutting the price of electric power used in the secondary industry from 1% to 10% in each scenario and in the service industry by 10% in all scenarios. The simulation is made by using the software of GAMS.

Shocks to Economy System

In every sector's production, electric power is one of the most important raw materials, and the policy of cutting the price of electric power used in the secondary and service industries

Table 1: Changes of sector output (%).

Sector Number	Target to cut price of electricity used in secondary industry									
	–1%	–2%	–3%	–4%	–5%	–6%	–7%	–8%	–9%	–10%
1	0.3	0.3	0.3	0.2	0.1	0.00	0.05	0.1	0.1	0.1
2	0.2	0.2	0.2	0.1	0.07	0.05	0.06	0.07	0.08	0.09
3	0.4	0.4	0.4	0.2	0.1	0.00	0.05	0.1	0.2	0.2
4	0.3	0.3	0.3	0.2	0.1	0.00	0.05	0.1	0.1	0.1
5	0.3	0.3	0.3	0.2	0.1	0.00	0.05	0.1	0.1	0.1
6	0.1	0.1	0.1	0.00	0.05	0.010	0.08	0.06	0.056	0.06
7	0.4	0.4	0.4	0.2	0.1	0.00	0.1	0.2	0.2	0.2
8	–0.4	–1	–1.6	–1.2	–0.8	–0.4	–0.65	–0.9	–0.1	–0.11
9	–0.4	–0.35	–0.3	–0.2	–0.1	0.00	–0.05	–0.1	–0.1	–0.01
10	1.24	1.295	1.35	0.86	0.52	0.18	0.36	0.54	0.6	0.66

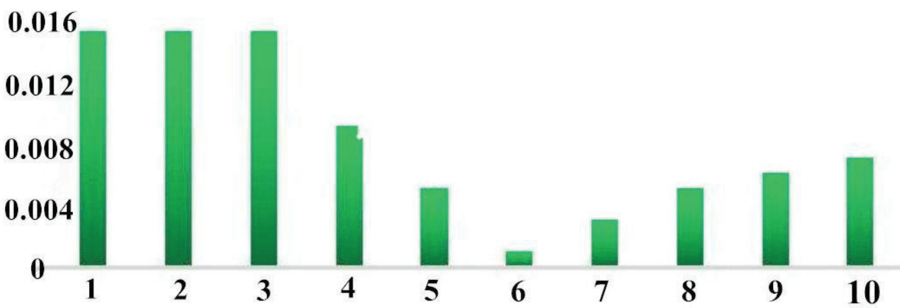

Fig. 2: Changes in GDP growth under different Scenarios.

will have an impact by changing the sectors' energy demands and outputs. Compared to the baseline scenario, the changes of sector output are shown in Table 1.

It can be seen in Table 1 that the impact on sector output is slight. Among the changes, the changes in output of coal (number 8) and electricity (10) are the most significant, and the change directions are as expected: as the price of electric power used in the secondary and service industries is reduced, an increasing demand for electric power is reasonable, and it will substitute the other energy forms (8 and 9).

Then we check the shocks on two key macroeconomic indicators, GDP growth and CPI change. Compared to the changes in GDP growth, CPI will hardly change under the policy. The changes in GDP growth are shown in Fig. 2.

It can be seen in Fig. 2 that GDP growth will be slightly increased by the policy to cut the price of electric power used in the secondary and service industries. When the target to cut the price of electric power used in the secondary industry is set from –1% to –3 % (scenarios 1, 2, and 3), the maximum effect on GDP growth is achieved (about 0.016%). The minimum effect on GDP growth is obtained when the target is set as –6% (scenario 6).

SHOCKS TO RESIDENTS' WELFARE

Besides the positive effects on sector production and the macroeconomic system, checks on economic welfare are also needed. The changes in welfare of residents' consumption (indicator: EV) and the cross-subsidy payment are shown in Fig. 3.

It can be seen in Fig. 3 that the policy to cut the price of electric power used in the secondary and service industries will increase residents' consumption welfare, while the cross-subsidy payment will decrease as an approximate linear decline. The maximum consumption welfare is obtained in scenarios 1, 2, and 3. As the cross-subsidy payment will decrease as an approximate linear decline, it may indicate that the more severe the policies are, the more resistance there will be from the agriculture.

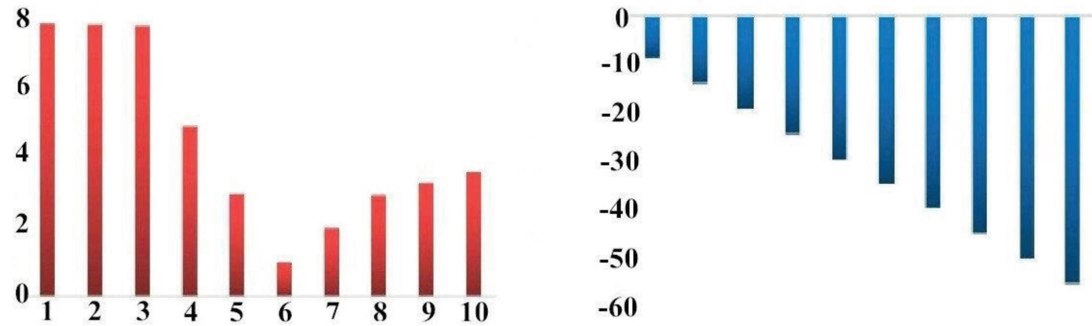

Fig. 3: Changes in EV and Cross-subsidy payment.

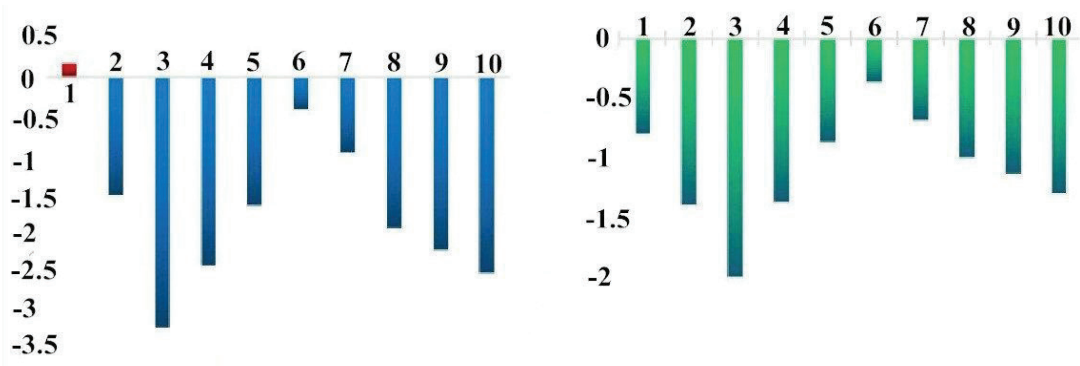

Fig. 4: Changes rates of $PM_{2.5}$ and CO_2

SHOCKS TO ENVIRONMENT

Besides the policy shock judgment from the economic view, policy shocks to the environment are equally important for comprehensive policy judgment. In Fig. 4, the policy effects on the abatement of $PM_{2.5}$ and carbon dioxide emissions are shown.

In Fig. 4, the change trends are shown as inverted U-shape curves, similar to the environmental Kuznets curve. Though the policy shocks are so slight that the maximum $PM_{2.5}$ emission abatement is only about 3.3%, while the maximum CO_2 emission abatement is only about 2%, the quantity of emission abatement is considerable, considering that CO_2 and $PM_{2.5}$ are emitted in quantities of 10 billion tons and 12 million tons, respectively, every year in China. In summary, it is obvious that the maximum positive environmental effects will be obtained when the target to cut the price of electric power used in the secondary industry is set as –3% (scenario 3).

CONCLUSIONS

This study uses the computable general equilibrium (CGE) model to study the issues of whether the policy to cut the price of electric power used in the secondary and service industries will benefit the economy and environment systems. The results show that, the electric power output will be slightly increased, the demand for coal will be reduced under the policy shocks, and the policy will contribute to the strategy of electricity substitution.

This substitution will lead to positive effects to the economic and environmental systems. The GDP growth will be slightly accelerated, and residents' welfare in consumption will be increased as well. Also, it will result in less emission of $PM_{2.5}$ and CO_2. By comparing the result curves, for the maximum positive effects, the price of electric power used in the secondary industry should be cut by –3%.

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